Alberta
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Branch

Some Research Studies on Energy Conservation in Housing

Projects supported in part by the Alberta/Canada Energy Resources Research Fund

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Foreword

Beginning in 1976, numerous projects were initiated in Alberta by industry and academic research institutions to help make better use of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rested with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities focused primarily on coal, energy conservation and renewable energy, and conventional energy resources. In 1988/89, a hydrogen research component was added.

Administration for the A/CERRF program was provided by staff within the Research and Technology Branch of Alberta Energy.

The A/CERRF program ended March 31, 1991. Although project funding has ceased, a series of technology transfer booklets, begun in 1986, continues to make research results available to industry and others who can use the information. This service will continue until all A/CERRF projects have been described.

For more information about other publications in the series, please refer to page 14.

Some Research Studies on Energy Conservation in Housing

Alberta Home Heating Research Facility.

In 1979, the Alberta Home Heating Research Facility was built south of Edmonton to provide a site for fundamental research on residential insulating and heating strategies appropriate for a northern climate. Funding for this test site was provided by A/CERRF.

The facility consists of six, single-storey housing modules, each measuring 6.8 m x 7.4 m in plan with full concrete basements. These uninhabited modules are located at the University of Alberta Farm at Ellerslie in a single east-west row. All are electrically heated. Five modules have the same exterior and roofing finish, while the sixth unit has masonry walls. Although five of the units have undergone modifications to allow various energy conservation concepts to be studied, one module, the Reference House, has remained unchanged since the beginning.

From 1980 to 1986, several research investigations were carried out at the facility. Most were concerned with heat transfer mechanisms that occur in residential buildings. The results from these studies led to some energy conservation options that are cost effective for the northern Alberta climate. The study methods used in this body of work, and the conclusions from it, were reported in 1987 in the technology transfer booklet Energy-Conserving Characteristics of Common Building Materials and Methods.

Beginning in 1987, a three-year project was initiated at the facility. As in the past, this study was conducted by the Department of Mechanical Engineering at the University of Alberta. It involved studies of four housing-related technologies:

- gas-fired absorption heat pumps;
- radiant floor-heating systems;
- passive ventilators; and
- moisture migration through structural components found in typical residential homes.

The results of these studies are reported here.

Gas-Fired Residential Heat Pumps

Devices known as heat pumps are capable of using low-grade energy available from the ground, the atmosphere and natural bodies of water, and they can be used to recover energy from various waste heat streams. As well, heat pumps can be used for both heating and cooling, giving them some potential advantages over systems that can be used either for heating or cooling, but not both.

The most commonly used heat pumps, however, use electrical power for the vapour compression cycle on which their operation depends. This can be costly. An alternative is to employ natural gas-fired absorption heat pumps. These devices are still being developed, but are suspected of being capable of providing heat for approximately the same cost as gas-fired forced-air heating systems, and they can provide low-cost air conditioning during warm weather.

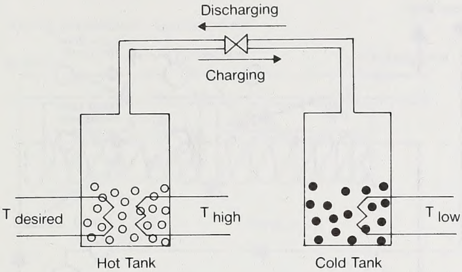
Thus, a project was initiated to obtain a gas-fired absorption heat pump and operate it under Alberta's climatic conditions.

A search of the scientific literature on heat pumps revealed that engine-driven heat pumps have been developed in Japan, Germany and The Netherlands, but only for commercial and industrial applications. Residential units installed in Germany were found to be expensive to operate and experienced some technical problems. The Gas Research Institute in the U.S.A. is currently developing units intended for residential use, but none is available at present.

Absorption heat pumps, which operate on an entirely different principle than do conventional vapour compression heat pumps, are still at an early stage of development. They employ a combination of working fluids called refrigerants and absorbers. This adds to their complexity and has delayed production of prototypes. Thus, units of this type also were not available for testing in Alberta.

The literature search also revealed that both types of heat pump are estimated to cost up to 1.5 times as much as electrically driven heat pumps. Also, they are not cost competitive with alternative heating and cooling systems when oil prices are relatively low. Nonetheless, heat pump use

Conceptual Operation of an Absorption Heat Pump



(Source: Development Status of Natural Gas Fired Residential Heat Pumps, Sadler, G.W. and K. Checkwitch, Department of Mechanical Engineering, University of Alberta, March 1988.)

worldwide has grown seven fold during the past decade.

While this project could not continue in the absence of a test unit, the state-of-the-art review showed that heat pump technology is continuing to advance in response to a growing market.

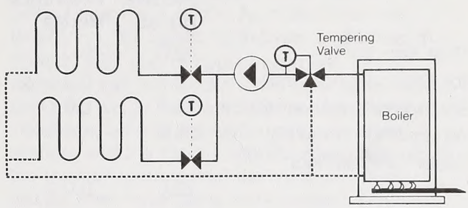
Radiant Panel Floor Heating

Radiant floor-heating systems are common in European homes, and are becoming widely used in North American commercial and industrial buildings that use slab-on-grade floors without basements. These systems are beginning to make some inroads into the residential sector in North America, as well. Thus, it was decided to conduct a study of radiant panel floor-heating systems and to compare them with conventional forced-air heating systems for residential use.

From an initial literature search, it was learned that floor-heating systems must be limited to a maximum surface temperature of 29°C for reasons of comfort. Therefore, the maximum heat output is limited to 100 W/m^2. This means that in Alberta homes with full basements, the building must be well insulated to achieve a uniform and comfortable air temperature from floor to ceiling during extreme weather conditions.

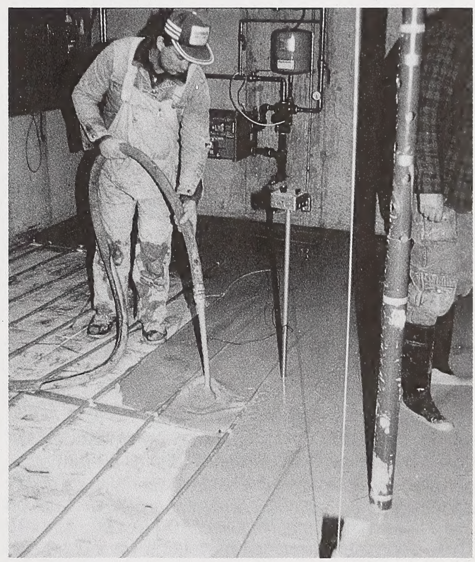
While suppliers of radiant floor-heating systems claim that energy savings up to 35 per cent and increased comfort levels relative to forced-air systems are possible, the scientific literature indicated an absence of well-documented test results. Hence, the study conducted at the Alberta Home Heating Research Facility addressed several concerns, including energy savings, interior air temperature profiles and the time required for the system to respond to changes in ambient conditions.

Basic Two-Zone Radiant-Panel Heating System



(Source: Research Needs in Radiant Panel Floor Heating, Dale, J.D. and M.Y. Ackerman, Department of Mechanical Engineering, University of Alberta, November 1987.)

In 1988, a radiant floor-heating system was installed in the "Passive House" at the facility. This module is insulated moderately well, and has large double-glazed windows on the south side. At the time of installation, the house had been used for five years to study passive solar heating systems, and its energy usage and operational characteristics were well known. As in previous studies, the Reference House was used as a basis for comparison.



One of two radiant floor-heating systems was installed in the basement floor, and covered by concrete, as shown here.

Test House Design Details

	Passive House	Reference House
Floor Area (m^2)	49.0	49.0
Total Window Area (m^2)	12.3	5.8
South Window Area (m^2)	11.1	0.0
Window/Floor Area (%)	25.0	11.9
South Window/Floor Area (%)	22.6	0.0
Insulation Level (RSI)		
Ceiling	7.04	2.11
Above-Grade Walls	3.52	1.76
Above-Grade Basement Walls	1.76	1.76
Below-Grade Basement Walls	1.76	1.76*
Basement Floor	0.88	none

* to 0.6 m below grade

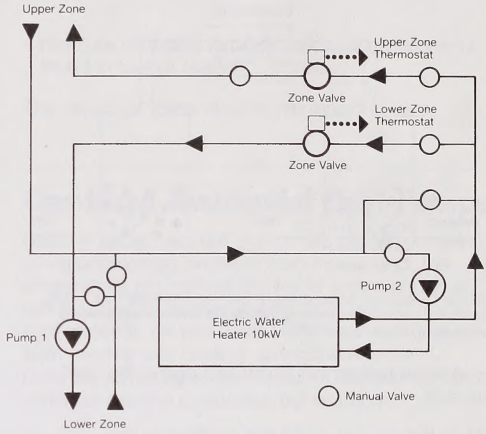
A radiant floor-heating system was installed on both the main floor and the basement floor of the test house, creating two heating zones. A 10 kW electric water heater supplied hot water to both assemblies, and wall-mounted thermostats and zone valves were used for temperature control.

The main floor installation comprised three "runs" of 12 mm polybutylene tubing, each approximately 70 m in length, connected to a single manifold/valve system. The tubing was suspended under the plywood subfloor between the floor joists, and each run was spaced approximately 200 mm apart, with slightly closer spacing under the south-facing window to help compensate for heat losses from the window. To minimize heat transfer to the basement zone, the tubing was backed with reflective foil and glass fibre insulation.

The basement installation comprised two runs of tubing, spaced 300 mm apart. It was embedded in 65-70 mm of gypsum cement laid over 25 mm of polystyrene insulation. The entire assembly was underlain by the original cement floor.

Three separate data-logging systems were used to monitor the performance of the floor and the house. The main facility logging system recorded overall energy use, as well as environmental parameters such as wind speed and direction, and solar radiation. The second data logger measured air infiltration in all six test houses, and the third monitored various aspects of the radiant panel floor-heating setup. All data-logging systems were controlled with either Hewlett-Packard 85 or IBM PC computers.

Schematic of Basic Two-Zone Radiant-Panel Heating System



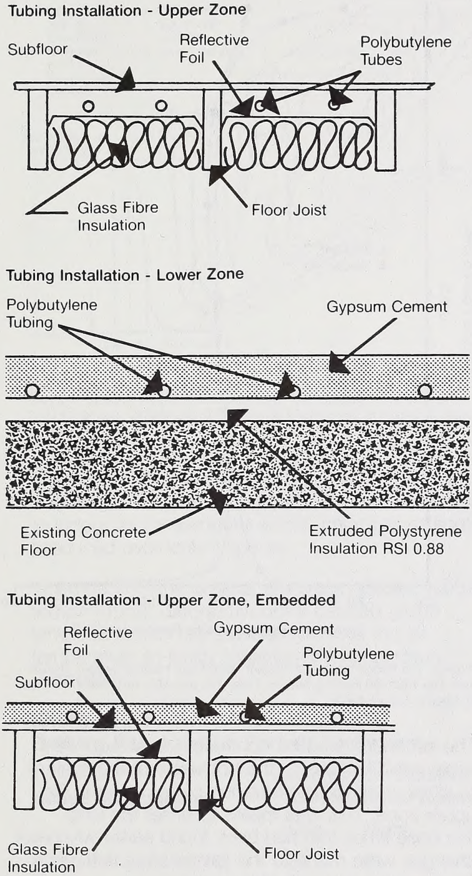
(Source: The Performance of a Radiant Panel Floor Heating System. Results from The 1987-88 Heating Season, Dale, J.D. and M.Y. Ackerman, University of Alberta, October 1988.)

Parameters measured were as follows:

- overall energy use;
- radiation transmitted through the south windows;
- wind speed and direction;
- ambient air temperature;
- energy supplied to water heater;
- zone air temperatures;
- vertical air temperature profiles;
- globe temperatures;
- zone supply and return water temperatures;
- zone water flow rates;
- basement floor heat losses;
- above-grade component heat losses and gains;
- below-floor ground temperatures; and
- ground temperatures outside basement walls.

The system was operated from March to December 1988, during which time solar gains were admitted to the house. It was found that the day and nighttime energy requirements were 38 per cent and 61 per cent, respectively, of the Reference House requirement. The overall energy usage was 52 per cent of that used by the Reference House. When solar gains were excluded, the overall energy use rose by 40 per cent to 70 per cent of the Reference House usage.

Panel Construction Showing the Location of Polybutylene Tubing and Insulation



(Source: The Performance of a Radiant Panel Floor Heating System. Results from The 1988-89 Heating Season, Dale, J.D. and M.Y. Ackerman, University of Alberta, August 1989.)

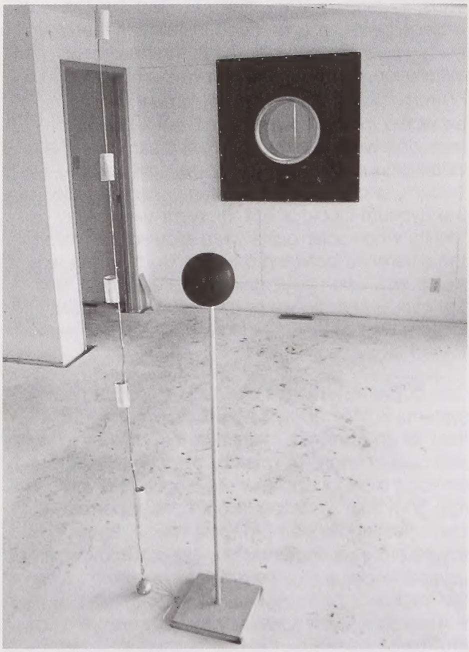
By comparison, when the test house was heated with the forced air system that had been in place before the radiant system was installed, and solar gains were excluded, energy usage was essentially identical to that of the radiant panel system. Thus, it appeared as though the effectiveness of the radiant-panel system was much the same as that of a forced-air system, but with some added difficulties. For example, it became evident that control using air temperature sensing was inadequate. Overheating occurred to an undesirable extent. Also, it was learned that a different strategy was necessary to accommodate the response of the radiant-panel system to changes in ambient temperatures.

Thus, in January 1989, the main floor system was replaced with an embedded installation that was placed over the subfloor. As in the basement installation, the plastic tubing was embedded in a 50-mm thick slab of gypsum cement. It was expected that the results when solar gains were excluded would be essentially the same for this installation as with the earlier radiant heating system, and the thermal storage characteristics of the gypsum would affect the night-versus-day results when solar gains were allowed. However, the difference between day and night results was much less when solar gains were excluded, and the overall energy use of the embedded radiant system was essentially identical to that of the forced-air system.

One of the advantages claimed for radiant heating systems is their ability to produce a comfortable thermal environment caused by having warm floors and cool ceilings. To quantify this characteristic, shielded thermocouples were placed in a vertical row from floor to ceiling in both the upper and lower heating zones of the test house, and temperature measurements were made over several weeks using the radiant system and then the forced-air system. The results showed that some minor differences between the temperature profiles produced by the two heating systems could be detected, but they were quite similar overall.

Measurements taken in a similar manner, and including floor temperature readings at certain horizontal distances from the south-facing window, showed that the radiant heating system was better able to compensate for cold air that cascaded down the wall below the window and moved across the floor.

Measurements were made of air temperature in the upper zone, and these readings were compared with measurements made with 150-mm diameter globe thermometers. This was done to determine whether the radiant system could reduce the sensation experienced by people of feeling cold even when the air temperature was at an acceptable level (often caused by the presence of a window in a room). Measurements were made 1 m and 3.25 m from the south-facing window. When the outside temperature varied between 0°C and -17°C, the forced-air system produced differences of approximately 1°C between the globe temperature and the air temperature at both locations. The differences were smaller for the radiant system. Therefore, its use should enhance the comfort of occupants. Because the test house is well insulated, the operation time of the radiant system was short. This did not allow the floor temperature to rise above the air temperature by more than 5°C, and was insufficient to raise the globe thermometer reading much above the air temperature.



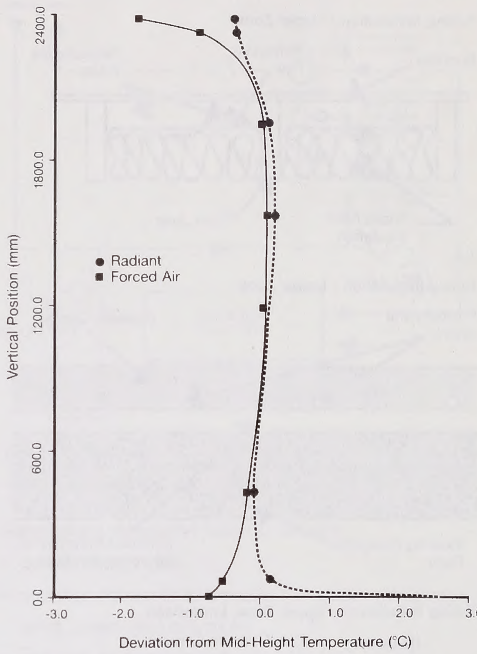
"Globe" temperatures and other measurements of temperature at various heights above the floor were used in assessing the performance of radiant floor-heating systems.

When measurements of heat loss through the basement floor were made, it was found that more heat was lost during operation of the radiant system than with the forced-air heating system. The contribution to overall energy use in the test house by heat loss through the basement floor when either the forced-air or radiant system was operated was five and 10 per cent, respectively.

Thus, after one full year of testing it was concluded that there was little difference between the radiant-panel floor-heating system and the forced-air system, even though the embedded radiant system should be more energy efficient. It was thought that the simple on/off control technique used for both heating systems might be inadequate to take full advantage of the thermal mass associated with the radiant system. Therefore, a series of experiments was begun to try various alternative control mechanisms.

The first method that was tested to improve the level of control involved using a multi-zone proportional controller to modulate each zone in response to a temperature error.

Air Temperature Measurements from Floor to Ceiling



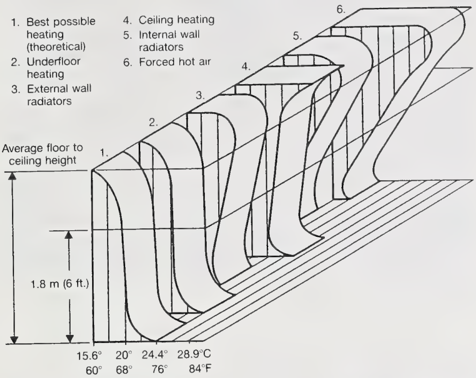
(Source: The Performance of a Radiant Panel Floor Heating System. Results from The 1988-89 Heating Season, Dale, J.D. and M.Y. Ackerman, University of Alberta, August 1989.)

The second alternative control strategy required some modifications to the hot water piping system to allow continuous circulation of hot water in the upper zone. This was meant to offset the long response times that had been found earlier whenever changes were made to the temperature settings. For example, the radiant-panel system was able to produce a temperature rise of only 1.5°C an hour, whereas the forced-air system under similar conditions produced a temperature rise of 13°C to 21°C in less than an hour.

It was found that all three control methods maintained acceptable temperatures within the upper zone of the test house. On/off control of zone valves using air temperature sensing thermostats proved to be adequate as long as the boiler temperature was set sufficiently high to meet the peak building requirement. It was also the most economical of all three.

The proportional controller that could reset the boiler temperature also produced suitable interior conditions and was capable of reducing the demand for energy to heat water.

Floor to Ceiling Temperature Profiles Produced by Various Heating Systems



(Source: Research Needs in Radiant Panel Floor Heating, Dale, J.D. and M.Y. Ackerman, Department of Mechanical Engineering, University of Alberta, November 1987.)

The continuous circulation strategy was the most sensitive to control settings, and the least sensitive to indoor air temperature errors. Improper settings produced overheated spaces.

While each of the control strategies affected globe temperatures differently, none caused globe temperatures to rise sufficiently above the air temperature to justify resetting the temperature controllers.

Energy Use: Radiant Panel versus Forced Air Systems

House Configuration	Energy Use Relative to the Reference House		
	Day	Night	Total
Radiant-Panel Heating (tubes in floor joist; no added mass)	38	61	52
Radiant-Panel Heating (solar gains excluded)	82	71	74
Forced-Air Heating (solar gains excluded)	81	68	72
Radiant-Panel Heating (embedded tubes; added mass; solar gains excluded)	74	71	72
Radiant-Panel Heating (embedded tubes; added mass; solar gains allowed)	34	61	50

The following conclusions were drawn from this investigation:

- no evidence could be found that radiant panel floor-heating systems are more energy efficient than conventional forced-air systems;
- the radiant systems produced uniform floor-to-ceiling temperature profiles, but the profiles resulting from the forced-air system were only slightly less uniform;
- the radiant systems produced higher globe temperatures than did the forced-air system;
- the radiant systems were more effective than the forced-air system in counteracting the cold plume that descends from windows when the outdoor temperature is quite low; and
- each of the three control strategies produced suitable interior conditions.

The economics of the two heating systems were not examined, primarily because there were no apparent energy savings to offset the additional cost of installing a radiant system. The study showed that incurring the extra cost of a radiant system might be justified on the basis of small improvements in comfort, but justification cannot be based on energy or monetary savings.

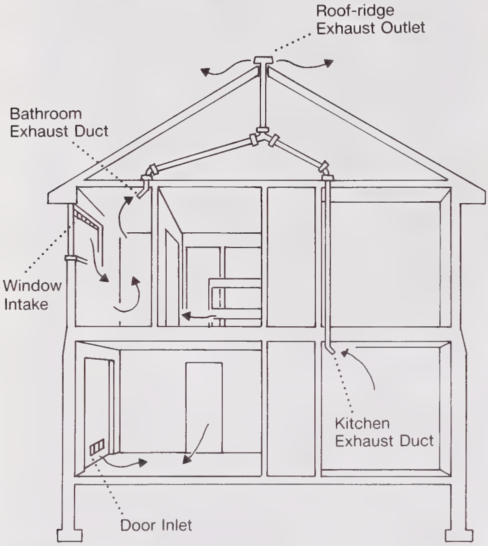
Passive Ventilation

The current Canadian Standards Association standard for residential ventilation requires an air exchange rate of 0.3 air changes an hour, to be provided by mechanical ventilation alone. This is perceived in some quarters as unduly restrictive and expensive because it makes no allowance for alternatives such as passive ventilation, which does not require mechanical assistance, or natural ventilation through leaks in the building envelope.

A study was undertaken at the Alberta Home Heating Research Facility to determine if passive ventilation represents a viable alternative or supplement to mechanical ventilation.

Initially, four test houses were equipped with passive ventilators located near ground level on the exposed south wall. These were openings through the above-ground portion of the concrete basement wall. Each was 15.2 cm in diameter and covered on the outside with window screen. In addition, a combination of open furnace flues and openings elsewhere in the structure was used in conjunction with the ground-level ventilators. A fifth house was used for reference. It had no passive intakes except for natural background leakage and an open furnace flue.

Totally Passive Ventilation System with Kitchen and Bathroom Exhaust Ducts



(Source: Passive Ventilation to Maintain Indoor Air Quality, Wilson, D.J. and I.S. Walker, Department of Mechanical Engineering, University of Alberta, 1991.)

Electrical dampers were used to open and close the passive ventilation inlets on the south walls over 4-, 6- and 24-hour cycles.

Originally, it was intended that measurements would be taken over a three-year period to determine the best locations for passive ventilation inlets and exhausts, and then develop control strategies to vary the air flow through passive ventilators to prevent over- or under-ventilation.

After the first year of operation it was evident that wind direction strongly influenced the degree of passive ventilation. The air flow rate changed by as much as four times as the wind shifted from blowing directly on the exposed south or north walls to the sheltered east or west sides. To account for wind and temperature effects, it would have been necessary to sort ventilation measurements into "bins" representing relatively constant wind direction; this would require 10 years to acquire and interpret the data.

Thus, to make more efficient use of the limited data that could be collected over the three-year study period, a computer model was developed. Its purpose was to predict the combined effects of passive ventilation and natural infiltration, and test the feasibility of various passive ventilation strategies. Measurements taken during the first year were used to refine and validate the model.

The computer model, called LOCALEAKS-2, determined the air flow through envelope leakage and passive ventilation openings by calculating the wind pressure on the exterior surfaces of a building. Adjustments were made to account for the influence of local shelter effects from upwind buildings and obstacles, and then the indoor-outdoor temperature difference was used to add a "stack effect" pressure to the wind pressure. This was followed by an initial estimate of the indoor air pressure, which allowed flow rates through structural leaks and passive ventilation openings to be calculated. The total inflow was subtracted from the total outflow, and if the flows did not balance, a new indoor air pressure was calculated. This process was repeated until the inflow and outflow rates balanced.

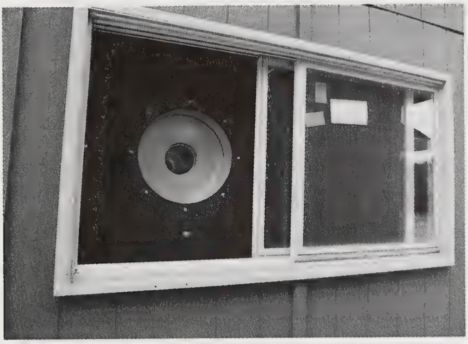
LOCALEAKS-2 was used to test various passive intake and exhaust locations on computer models of three different types of houses:

- a small 100 m^2 single-storey bungalow with exhaust and intakes distributed around its perimeter;
- a large 200 m^2 two-storey house with high and low passive ventilation intake and exhaust locations; and
- a 200 m^2 central unit of a row house complex, with leakage and passive ventilation sites on the front and back walls, and no leakage on the side walls connecting adjacent units.

In addition to varying the location and size of passive ventilation openings, the effect of wind shelter from nearby buildings was also simulated.

The following general observations were made from these computer simulations:

- passive ventilation is strongly dependent on wind speed, direction and upwind sheltering by nearby buildings;
- natural air infiltration without passive ventilation will provide adequate ventilation in most houses during the winter months;
- townhouses with only two exposed walls probably will require supplementary passive vent openings to meet ventilation standards;
- a standard furnace flue, with its rain cap located above the roof ridge, provides an efficient, passive ventilation exhaust; and
- passive ventilation will not be effective during spring and fall unless wind speeds are higher than 10 km/h.

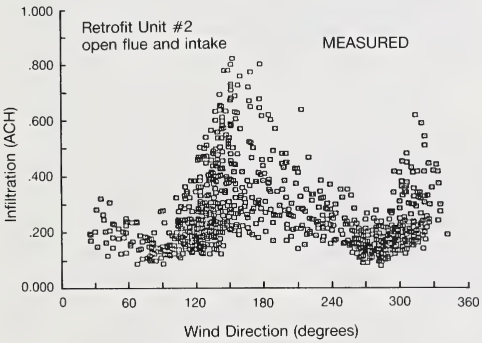


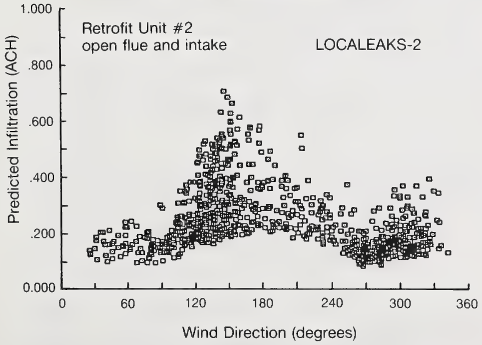
Passive ventilators installed in test modules were used as alternatives to mechanical heat-recovery ventilators.

This picture shows a unit installed in a window opening.

This picture shows a unit installed near ground level.

Example of Measured and Predicted Effects of Wind Direction on Passive Ventilation





(Source: Passive Ventilation to Maintain Indoor Air Quality, Wilson, D.J. and I.S. Walker, Department of Mechanical Engineering, University of Alberta, 1991.)

The simulation of air infiltration and ventilation rates in three types of houses led to several conclusions about the best strategy to provide adequate ventilation for indoor air quality and avoid over-ventilation and high energy costs during the winter. These conclusions were as follows:

- most detached, single storey and two-storey houses are adequately ventilated in winter by natural air infiltration and require no passive ventilation;
- townhouses, with two walls common to adjacent units, are usually not adequately ventilated by natural infiltration;
- even with several large, ground-level, passive ventilation openings, most houses cannot be ventilated adequately in summer, and during the spring and fall seasons in light winds without using large vents that cause over-ventilation in the winter; and
- before passive ventilation can become a common feature of residential housing, it is necessary to design and make available an inlet damper control that is regulated by outdoor temperature and wind speed.

Overall, it was concluded that carefully located passive ventilation inlets and exhausts equipped with thermostatic dampers can provide a viable alternative to energy-consuming mechanical ventilation systems that are expensive to maintain. Although damper-equipped passive ventilators could cost more than mechanical ventilators initially, they should require little maintenance, and should be both quiet and reliable.

Moisture Accumulation in a Building

The occurrence of moisture in the envelope of a building can lead to a range of problems, some of which are mostly an inconvenience, while others can be more serious and lead to structural damage. Virtually all these problems stem from the climatic conditions prevalent throughout Canada during the winter months. There are five types of common problems:

- mould and mildew growth;
- exterior siding damage;
- window condensation;
- attic condensation; and
- concealed condensation in wall cavities.

All these problems arise from a combination of indoor conditions, winter climate and construction details. Thus, it is important to understand the mechanisms by which moisture migrates through the envelope of a building and causes such problems.

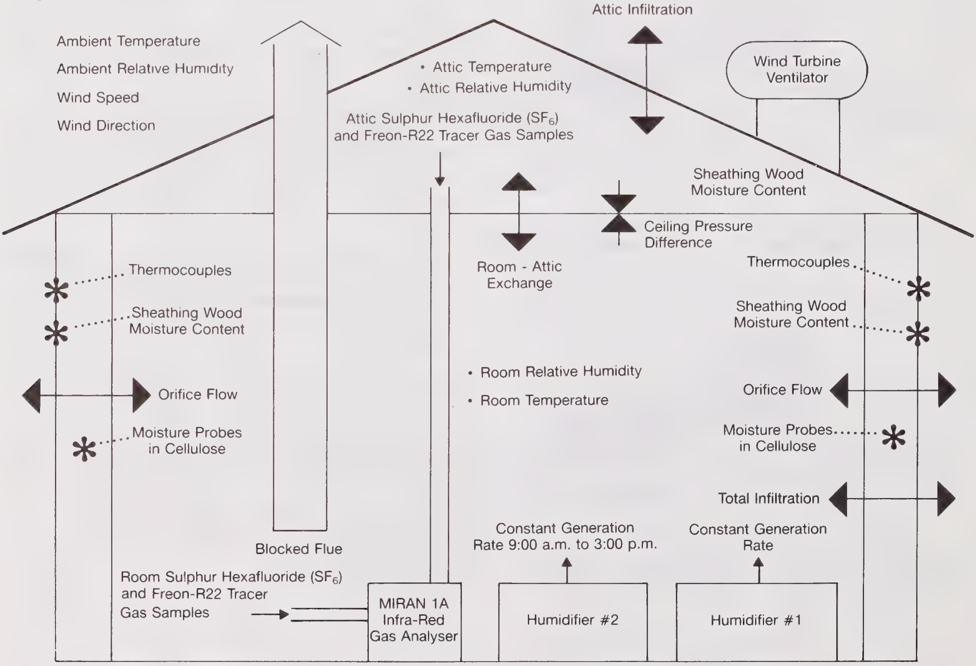
From a review of the technical literature, it was noted that moisture is transported through a building envelope by three mechanisms:

- diffusion of water vapour;
- direct movement of moist air by a pressure difference; and
- water forced into the envelope, usually by wind-driven rain.

While these explanations seem logical enough, the mechanics of moisture transport are complex and have not been well studied, particularly in a climate like Alberta's.

Consequently, a research program was initiated at the Alberta Home Heating Research Facility in which the relative humidity inside one test module was controlled at 40 per cent, and then the migration of moist air into or out of the module was measured. Also monitored were indoor and outdoor temperature, as well as wind speed and direction. The natural infiltration rate for the module was measured with a tracer gas. All monitored data were recorded and averaged using a computer.

Variables Measured in the Moisture Migration Study



(Source: Moisture Accumulation in a Building Envelope, Final Report, Forest, T.W., I.S. Walker and K. Checkwitch, Department of Mechanical Engineering, University of Alberta, 1991.)

Initial measurements of moisture migration rate were performed by attaching a calibrated orifice plate to the existing 15.2-cm diameter flue in the module and measuring the incoming and outgoing flow rate. It was found that the infiltration rate was somewhat greater than the flue flow rate during January and February 1988. Thus, it was concluded that some moisture must be migrating through the building envelope. It was calculated that the rate of moisture migration through the building envelope was 0.7 kg of water a day.

In March 1988, the flue was blocked, and the indoor moisture generation rate required to maintain a relative humidity of 40 per cent was reduced to 3.4 kg a day from an initial rate of 5.5 kg a day.

To measure the amount of moisture accumulating in the wall cavity, two specially designed wall panels were built and installed, one each in the north and south walls. Each measured 117 cm by 234 cm and was constructed of interior drywall, polyethylene vapour retarder, glass fibre insulation and exterior plywood sheathing. A 0.95-cm diameter hole was drilled at the centre line of each panel to allow passage of moist air. The panels were instrumented to measure air flow, temperature profile and moisture accumulation. Because it was expected that most moisture would accumulate at the interface between the insulation and the exterior sheathing, an array of removable wooden plugs was cut from the plywood exterior of each panel. By determining the initial dry weight of every plug, and then reweighing them throughout the test period, the amount of moisture accumulation at the insulation/sheathing interface could be measured.

During the winter test period, no evidence was found of moisture accumulation in the insulation. The small amount detected in the walls was found in the exterior sheathing on the north side. In contrast, any moisture accumulation in the south panel was driven off by solar heating. The accumulation in both wall panels was the direct result of air exfiltrating through the wall cavity.

Modifications were made to the test house for the 1988/89 heating season. Instead of maintaining a constant indoor relative humidity, the moisture generation rate was kept constant and the relative humidity was allowed to fluctuate with natural air infiltration. During the 1989/90 heating season, moisture release rates were maintained at 4.4 kg/day throughout the day, and were raised to 8.6 kg/day between 9:00 a.m. and 3:00 p.m. to simulate normal occupancy effects caused by cooking and washing.

Pre-weighed wooden plugs accessible from the outside of one test module were used to determine the amount of moisture that migrated from the inside to the outside of above-ground walls.

The single-wall test panels used initially were replaced with four side-by-side assemblies on each of the north and south walls. Half were filled with glass fibre insulation, while the other half contained wet, sprayed cellulose insulation. Also, for each type of insulation, two panels were tested; one with conventional exterior plywood sheathing and the other with a vented gap between the insulation and the exterior sheathing.

It was found that the flow rates for infiltrating air were approximately twice those of exfiltrating air. The direction of flow through the panels was determined mainly by the wind direction, with infiltration through the windward panels and exfiltration through the leeward panels. Air flows through the unvented panel were one-quarter to one-fifth those passing through the vented panel. Although initial measurements of flow rates through the cellulose insulation were comparable to those through the glass fibre insulation, the cellulose eventually achieved a 20 to 30 per cent higher flow resistance. This was attributed to the cellulose having lost its initial moisture as the heating season progressed.

Throughout the heating season, no steady rise in the moisture level in the sheathing was noted. Instead, the sheathing absorbed and released moisture over short periods, reaching a high of 16 per cent moisture content in the north-side panels. Moisture absorption was correlated directly with periods of significant air exfiltration during cold weather, while desorption occurred when temperatures moderated.

The attic space of the test module was studied also to determine the effect of attic vent location on moisture migration. Instruments were installed to measure attic ventilation rates, indoor/attic exchange rates, attic temperature and relative humidity, and the moisture content of the roof sheathing. Two attic ventilation configurations were used: gable-end vents; and a combination of soffit vents along the eaves and a roof-mounted turbine ventilator.

While ventilation rates were found to be strongly influenced by wind direction and speed, it was also noted that the combination soffit/turbine arrangement resulted in higher ventilation rates than did the gable-end ventilators, regardless of wind direction.

Most of the moisture delivered to the attic space was the result of air exchange between the attic and the room below. The magnitude and direction of this flow were found to be weakly correlated with indoor/outdoor temperature difference, and uncorrelated with wind speed. Over the entire 1989/90 heating season, approximately 140 kg of moisture entered the attic from the rest of the building. If the attic had not been provided with proper ventilation, this volume of moisture might have caused excessive moisture buildup in the wood.

As in the study of moisture accumulation in walls, it was found that moisture accumulated in the wooden roof trusses and roof sheathing when the outdoor temperature was low, but this moisture was released when temperatures rose. The moisture content of the roof sheathing was lower than that of the wall sheathing, despite the large volume of water that entered the attic.

The large data base resulting from this study led to the development of a computer model of indoor air infiltration. In its current configuration, the model includes effects caused by distributed air leakage, flues, windows and mechanical ventilation. Future work will include the attic as a separate zone from the interior of the house.

Development of a model of moisture deposition in walls has begun. The objective is to predict the seasonal moisture accumulation in, and removal from, exterior sheathing.

Further Reading

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Contact

For additional details about the current study and all previous investigations at the Alberta Home Heating Research Facility, contact:

Dr. J.D. Dale
Professor
4-9 Mechanical Engineering Building
Department of Mechanical Engineering
University of Alberta
Edmonton, Alberta
T6G 2G8

Telephone: (403) 492-3598

This is the final publication describing energy conservation research funded by A/CERRF. For information about the current energy research interests of the Alberta Department of Energy, contact:

Director, Hydrogen Research and Technology
Research and Technology Branch
Alberta Energy
11th Floor, North Petroleum Plaza
9945 - 108 Street
Edmonton, Alberta
T5K 2G6

Telephone: (403) 427-3713
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Main Floor, Britannia Bldg.
703 - 6th Avenue S.W.
Calgary, Alberta
T2P 0T9

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